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CONSTRUCTION OF GRANBY PUMPING PLANT

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CONSTRUCTION DIVISION

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THE GRANBY PUMPING PLANT

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Plant Construction

General

The Granby Pumping Plant on the north shore of Granby Reservoir is situated adjacent to Soda Creek, a small tributary of the Colorado River. Location of the plant in such a position provides access to high ground north of the plant with a minimum of closed conduit, and access to the reservoir floor by excavating 115 feet deep on the left bank of the creek and constructing three 518-foot-long intake conduits.

Construction of the plant was begun March 31,1947, and completed in the late Fall of 1950. Actually, the major concrete work on the building proper was completed a year earlier, in the Fall of 1949. The principal work remaining to be completed in 1950 was the plant parapet, the embedment of pumps, and other second-stage concrete work, such as the placement of the bonded floor topping. Other construction remaining in 1950 consisted of a cable tunnel from the plant to the switchyard, the switchyard structure foundations, and the final dressing of the area.

Construction By Contract

The Granby Constructors, a joint venture group, organized purposely for construction of Granby Dam in 1946, bid upon and were successful in obtaining the contract for construction of the pumping plant and its appurtenant works. The group was comprised of seven individual contracting firms.

Included in the contract were the plant building, the three 7-foot 3-inch internal diameters, reinforced-concrete intake conduits, and the intake structure; the 11-foot internal-diameter reinforced-concrete discharge conduit; and the silt retention and diversion facilities, consisting of an earth dike on Soda Creek, upstream from the intake structure, and a 1/2-mile-long diversion channel from Soda Creek to adjacent Stillwater Creek. The contract did not provide for installation of the pumps, motors, operating equipment, nor for such facilities as the heating, ventilating, and electrical control apparatus. This was accomplished by separate contract upon completion of the major concrete construction in 1949.

Originally, a large steel surge tank was contemplated for construction under the general contract, but this was later eliminated by a change in the design of the discharge conduits and deleted from the contract.

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Progress

Rapid progress was made the first year in excavation, but steel shortages and consequent late delivery of embedded materials resulted in a considerable delay in the concrete work. Steel reinforcement supplied by the contractor was particularly in short supply and obtainable only by weeks or months of advanced planning and scheduling with steel mills. Equipment manufacturers, because of the steel shortage, were reluctant to set firm delivery dates, and the designs necessarily suffered. In some instances, the designs had to be changed to accommodate changes made in an effort to utilize existing equipment or to make alterations in other equipment. All these factors contributed to an additional year's time in construction.

The weather played an important part in the construction work. Winters are severe in the subartic, or alpine, region of the western Rocky Mountains above elevation 8000, and impose a limit on the working season. Frost penetrates to depths of 6 to 7 feet; temperatures of 10° to 40° below zero are common; and a snow depth of 3 to 4 feet is not uncommon. Concrete can only be placed 4 or 4-1/2 months out of the year without elaborate and expensive protection. Excavation and earthwork is generally impossible between November 10 and May 10. The years 1947 and 1948 followed the usual weather pattern, but an open fall in 1949 contributed materially to the progress made.

Construction Facilities

General

While the contractor was proceeding with the excavation in 1947, several plant and office buildings were constructed. A quonset hut was assembled for use as office space. A fully automatic batching and mixing plant was erected. A carpenter shop fashioned from a surplus plane hanger, consisting of steel framework covered by canvas was set up, and a small utility building which housed compressors, a small parts room, and pipe and electrical shops was also built. A frame warehouse for the storage of Government-furnished materials completed the construction plant buildings during the first year.

In 1948 a gantry-type crane, employed during the war in the West Coast ship building program, was purchased and shipped to Granby. Upon arrival it was converted into a Whirley-type crane and installed at the pumping plant, after first constructing a steel substructure, Figure 5. In 1949, upon the completion of Granby Dam, a small truck repair shop was set up at the plant to service and maintain the excavation and hauling equipment. Previously, repair and maintenance work had been accomplished at the contractor's well-equipped shops at the dam.

Excavation equipment consisted of numerous draglines, power shovels, carryalls, and scrapers. Hauling equipment, in addition to the carryalls, consisted of 10- and 13-cubic-yard bottom- and end-dump trucks. This equipment was utilized on both Granby Dam and the pumping plant as the need arose and was shifted frequently.

Labor

Securing and maintaining an adequate force of skilled and unskilled labor for the work was a problem to most contractors in the area. It might be said they moved in and out with the weather. During the summer months, many college men were available to supplement the normal labor supply. These,

as well as others, left with the cool weather to return to school, in the case of the students, or to the fall harvests. In an attempt to secure sufficient labor, the contractor maintained contact with employment offices in all sections of Colorado; in the adjoining states of Kansas, Wyoming, Nebraska, Utah, and as far south as Texas. Although strikes did not hamper the work on the western slope as much as they did on the eastern slope of Colorado, a strike of steel workers in the Spring of 1948 delayed erection of the Colby crane sufficiently to materially affect the progress for that season. A second altercation with steel workers affected the placement of reinforcement and resulted in a subsequent delay.

During the first year, a large force of carpenters, steel workers, and laborers were employed on the day shift; a small force on swing shift performed clean-up, sandblasting, and odd jobs; and only sufficient men to carry on essential work, such as curing, heating, and minor jobs, were placed on the night shift. In general, crews worked a 6- or 7-day week. The second season saw a larger force at work with construction under way on the plant, intake, and discharge conduits, and intake structure. During this season and the following one, the largest carpenter and steel forces were employed on the day shift, although a somewhat smaller carpenter force worked the swing shift and night shift. Concrete placement usually began on the late day shift or with the beginning of the swing shift, and continued on into the night shift or until completed.

Construction Operations

Excavation

Major excavation under the contract included that for the plant building, the intake structure, the intake and discharge conduits, that necessary for the foundation of Soda Creek Diversion Dike and Diversion Channel, for the excavation of fill materials, and removal of the top portion of a hill east of the plant to prevent its sliding into the intake channel and structure. Approximately 275,000 cubic yards were involved in the 115-foot-deep excavation for the plant proper and the adjacent intake and steel-encased discharge conduits.

Pumping Plant

The first work on the pumping plant was begun on March 31, 1947, by removal of 1 to 2 feet of snow in the plant area, the clearing of sagebrush and a few trees, and the stripping of organic material.

The excavation was carried out essentially and as nearly as possible according to the material encountered. The first cut, varying in depth from 1 to 8 feet, provided for removal of a mixture of clay, silt, gravel, and cobbles. This material was stock piled for future use in compacted fills.

A second cut carried the excavation to the bedrock of the area and the material removed consisted of silty-sandy gravel, cobbles and boulders. This material also was stock piled for later use as sluiced backfill.

The balance of the excavation was in the North Park formation, which consists of thin-bedded, fractured, loosely cemented sand, silt, and clay stone of variable hardness and referred to during construction as siltstone. For this work the draglines were converted to shovels. Light blasting of the siltstone was attempted, but abandoned because of the unsatisfactory

results obtained due to the fractured condition and the variable hardness of the formation. However, the shovels were able to dig the siltstone effectively, and little difficulty was encountered in the excavation work, so far as the hardness of the siltstone was concerned. The plant excavation was staked on a 1:1 slope in both the siltstone and overburden.

During the excavation of the siltstone, several minor faults were revealed. Upon intersecting these, many small slides and one of major proportions occurred. Approximately 960 cubic yards of additional excavation is attributed to removal of the slides, and the overhanging drummy and loosely consolidated siltstone, which had to be barred and loosened to avoid a hazard or damage to the work.

The only other problem encountered in the excavation for the plant and the adjoining intake conduits was brought about primarily from the seepage of irrigation water and drainage water. Within the plant area, this water was collected in a sump at the east end of the plant excavation and caused little difficulty. However, in the area of the intake conduits, infiltrating water as well as surface drainage caused a softening of some of the siltstone, bogging equipment. Major excavation for the plant and intake conduits was completed June 3, 1947. The balance of the excavation involved for the intake conduits and intake trashrack structure was completed the following year.

Discharge Conduit

Excavation for the discharge conduit also was begun on April 3, 1947, using a 2-1/2-cubic-yard dragline and shovel. The excavation area outlined by the slope stakes was first stripped of all organic material, and then the clay overburden. This latter varied from 1 to 6 feet in depth, and was removed and stock piled along the trench. The gravelly and cobbly material underlying the clay was then excavated and placed behind the clay and stock piled for future use. The material was segregated in this manner so that it might be used for back fill. With the exception of the excavation for the three concrete-encased steel discharge pipes, the steel-encased Y branch and the first few sections of the discharge conduit, all excavation for this feature was above the siltstone.

Soda Creek Diversion Channel and Dike

On April 19, 1947, a 2-1/2-cubic-yard dragline started excavation for the Soda Creek Diversion Channel at the Stillwater Creek end. Twelve-cubic-yard carryalls pulled by tractors assisted in the excavation by stripping the organic material from the surface. Here again the clay overburden was then removed and stock piled for use in the building of the zoned dike. The dragline then excavated the remaining material, mostly a mixture of clay, silt, sand, gravel, and cobbles, segregating it for possible use in the dike. Some siltstone was encountered in the bottom of the diversion channel, but it required no special blasting for removal. The foundation for the dike consisted generally of a gray clay, with some thin gravel layers dispersed throughout, and with siltstone near the south abutment. The upper portion of the abutments were primarily alluvium, reasonably well graded from clay-size particles to boulders.

Preparation of Foundations

The foundation for the pumping plant proper and the adjacent intake conduit was roughed out by power shovel. The outline of the substructure for the plant was then staked, and the siltstone trimmed to neat lines with power spades and hand tools. To avoid any possible disturbance to the material no blasting was permitted in the excavation of the siltstone as it approached neat foundation lines for the substructure. All loose fragments and drummy siltstone was removed by hand. The mud was removed by hand scraping with shovels and by the use of air-water jets. Asphalt emulsion was at first applied to the exposed siltstone foundation to reduce air and water slaking, but the results were not too gratifying, especially where the siltstone had become moist from seepage. In these damp areas, the emulsion bonded poorly with the siltstone. Approximately one-half of the foundation was covered with the emulsion, as called for in the specifications, and it was dusted with cement to prevent it from sticking to the workmen's feet. However, even with care, it peeled off by the time forms were ready for the placement of concrete. The use of the emulsion was therefore abandoned and instead the foundation kept dampened at all times in an effort to reduce the slaking. Just prior to placement of concrete, a final foundation clean-up was performed by the use of air and water jetting.

A similar procedure was followed in the preparation of the siltstone foundation for the intake conduits, except in overexcavated areas where seepage was a problem. In these areas, gravel drains were provided on top the siltstone prior to the placement of concrete.

In preparation for the placement of concrete for the discharge conduit, all rock over 3 inches in diameter was removed from the surface, and it was thoroughly dampened prior to compaction with a one-drum sheepsfoot-type roller. Where overexcavated, an 8-inch layer of clay was placed and rolled. If necessary, additional 8-inch layers of clay were consolidated until the foundation had been brought to desired grade. Sufficiency of compaction of the clay was determined by field density tests.

Preparation of the foundation for the Soda Creek Dike was one of dewatering and removal of loose material on the blue clay or siltstone foundation. Cofferdams placed upstream and downstream from the dike foundation area were employed and the water within the area pumped out.

Forming

The forms employed in the construction of the pumping plant and its appurtenant works varied considerably. Wooden forms were used throughout the plant building, with the stipulation that they be fabricated in such a manner to produce board form marks running either horizontally or vertically between major breaks within the plant, such as between the floor at one elevation and the ceiling above. Shop-fabricated panels were employed extensively. For the substructure, 2- by 6- and 2- by 8-inch studs, sheeted in a horizontal direction, with 6-inch shiplap were employed and the forms braced externally. Panels constructed with the shiplap sheeting running in a vertical direction were used to form the exterior walls and buttresses on the intermediate structure of the plant. Most of the interior walls were formed with shop-fabricated panels in whcih the sheeting ran horizontally.

Various types of form ties were employed in the early part of the work, but most of them were discarded in favor of the conventional "she-bolt" ties.

After the first few concrete placements, little difficulty was encountered in holding the forms in place. Some revision of the location of tie rods helped materially in this respect.

The usual bracing, scaffolding, and supports were provided for the floors and beams, but the somewhat novel use of native pine logs was an innovation employed by the contractor. The native logs were used almost exclusively for the bridging and staging in support of the floor at elevation 8252.50 which was approximately 41 feet above the next lower floor. To support this floor and its beams, the native timbers were fabricated into bents, cross braced securely and properly capped. At first, there was some concern regarding the amount of settlement that might occur in the use of the "green" timbers, due to the drying shrinkage, but careful checks disclosed nothing unusual.

Except as noted, steel forms were employed in constructing the discharge and intake conduits and were of the conventional type. The interior forms were collapsible, with the invert section omitted; that for the intake conduits being 7 feet 3 inches in diameter and 25 feet long. In this instance the form was supported by a needle beam approximately 55 feet in length. The beam was supported by a screw jack at each end and to move the form from one location and set it in the next adjacent section the jacks were released and the needle beam, attached to and held in place by the form, was rolled ahead and reset. The form was then collapsed and moved forward. The forms were used as designed, except for the bolting of two plates adjacent to the lower end to reduce the invert opening of 13 inches to prevent fresh concrete from "boiling" up into the invert during placement operations.

The concrete thickness of the intake conduits under maximum backfill load was 27 inches. The balance was 18 inches. The contractor was successfull in securing sufficient exterior steel forms for the 18-inch-thick intake conduits, but due to the steel shortage it was not possible to secure steel exterior forms for the 27-inch-thick portions of the conduits. At first, a wooden form lined with sheet steel was fabricated for the thicker conduit sections. The form did not strip easily, racked, and required that a wooden bulkhead be constructed for each individual placement. As a result, its use was abandoned and instead the 18-inch forms were remodeled slightly, by adding a wooden section to the bottom. This metal form, together with a metal bulkhead, proved to be very satisfactory, and progress of the work was much improved. The exterior and interior forms for the intake conduits were held apart by temporary wooden spreaders which were removed as the placement of concrete progressed. "She-bolt" tie rods were used to hold the forms together. The tie rods as originally designed, were insufficient in number and exterior bracing was necessary to prevent movement.

Forms similar to those employed in construction of the intake conduits also were used in construction of the discharge conduits. The inside form in this instance was 11 feet in diameter and 24 feet 6 inches in length. In place of a steel plate to reduce the "boiling" of fresh concrete into the invert, "boil strips," consisting of a 2- by 6-inch piece of lumber was bolted to the lower edge of the form and extended downward into the fresh concrete. Tie rods and spreaders similar to those used with the intake conduit forms were used. To eliminate external bracing, an additional row of tie rods was placed along the bottom of the outside form. Little trouble was encountered from the forms "floating."

All horizontal and vertical bends were formed, for the most part with wooden shop-fabricated interior forms and built-in-place exterior forms. The wood forms for all the work were well designed and fabricated. Their use both simplified and expedited construction.

All forms were treated with appropriate types of form oil. Steel forms stripped easily and with only a minor amount of damage to formed surfaces, unless the form was left in place over a long period of time. As an experiment, some of the interior plant forms were given a coating of plastic. This was tried in an effort to reduce the work necessary in cleaning and preparation of the forms for reuse and to prolong their use. The extra expense of applying the plastic and the care of the forms thus coated was not considered justifiable and its use was discontinued.

Reinforcement

In accordance with the specifications, the contractor furnished all reinforcement bars. They were purchased cut and bent from a supplier in Denver. Because of the steel shortage and the time spent in cutting and bending, shipping, and subsequent fabrication on the job, it was necessary for the contractor to schedule the rolling of reinforcement with the steel mills at least 2 months in advance of each concrete placement.

The fabrication and placement of reinforcing was subcontracted to the Ogden Construction Company of Roanoke, Virginia. Upon receiving the cut and bent steel, the subcontractor fabricated the cages necessary for the intake and discharge conduits, and, where possible, mats for various portions of the plant and its appurtenances. This work was done in a steel yard adjacent to the plant building. The fabricated cages and mats were then transported on a low-boy truck and set into place by either a dragline, in the case of the conduits, or by the crane in the case of the plant.

Design required that splicing of reinforcement bars be held to a minimum. Most of the steel within the plant was placed and tied by hand. Minimizing the vertical splices, oftentimes resulted in steel extending 20 to 30 feet above the previous placement, thereby complicating form erection, concrete placement, and the movement of materials from one bay of the plant to another.

Embedded Materials

As in all structures of its kind, there were numerous and sundry materials to be embedded within the concrete of the plant, including metal sealing strips, metal water stops, asphalt seals, pump intake pipes, cast iron drain tile, pipe sleeves, copper tubing, grout tubing and fittings, metal inserts, anchor bolts, both metal and transite electrical conduit, ground wires, etc. Other than the work involved in placing the embedded materials being time consuming and complicated by the heavily reinforced walls, floors, and beams, not too much difficulty was encountered.

Watertightness was a prime requisite in construction of the plant, the lower 133 feet of which is below maximum high-water surface of Granby Reservoir. Construction joints were held to a minumum commensurate with the type of design used, as noted in Figure 9, and all horizontal joints were provided with a metal water stop. The only vertical joints in the exterior walls below water level are those between the rectangular section of the plant and the semicircular arch rings at each end, and of course those between the intake and discharge conduits and the plant building. All other vertical construction joints were placed in the interior cross walls.

In addition to monel-metal and stainless-steel water seals, asphalt seals were provided in the vertical and horizontal construction joints of the 8-sectional base slab. The asphalt seal was built in each construction joint

of the substructure by forming a 5-1/2-inch-square opening. The block out was formed for the first half of the opening, in the other half, in the adjacent block, sheet steel embedded in the concrete formed the opening. A system of 1/2-inch pipe was also embedded in this block out, so that when necessary, steam could be circulated in the opening to warm the concrete and asphalt placed in the block out. Results accomplished were very satisfactory.

Difficulty was encountered at first in the welding of the monel-metal and stainless-steel sealing strips for the substructure blocks. The strips were bent according to drawings and the joints of half of the strip to be embedded in the first placement were welded. The half to be embedded in the second block was bent 90° and loosely tacked to the forms with the joints unwelded. Upon stripping the forms and rebending the strips to their normal position, an attempt was made to weld the remaining half of the joints. Numerous pin holes and cracks continued to develop in the welds. Welders experienced with monel metal and stainless steel were called on to demonstrate the proper flux, flame, and procedure to be used and some improvement resulted. Finally, however, it was concluded that the heat of the welding expanded the exposed metal, while that embedded in the previous block was held rigid, causing distress and cracking. So much difficulty was causing delay to the work. The contractor decided to try welding all except the corner joints before embedding the first half of the strip. This resulted in only a minor amount of difficulty and delay thereafter.

To determine the effectiveness of the welds in metal water-sealing strips, they were tested by smearing the weld with soap suds and blowing compressed air on the other side. Any holes in the welds permitted the air to come through, making a soap bubble.

Horizontal coils of 1-inch outside-diameter, thin-wall tubing were used to cool the concrete. Two series of coils were placed in each block of the substructure, one in the center and the other near the bottom. Coils of tubing were also placed in the buttresses at horizontal intervals of 3 feet. Before placement of concrete, all tubing was tested for leaks under 100 pounds of air pressure.

Concrete Production

Aggregate for the concrete work had been produced under earlier contracts from river deposits about a mile below Grand Lake on the Colorado River prior to its inundation by Shadow Mountain Reservoir. The aggregate had been transported to the pumping plant area and stock-piled in five sizes. They were: sand (0 to 3/16-inch); and 3/16- to 1/2-inch, 1/2- to 1-inch, and 1- to 2-inch, and 1/2- to 1-1/2-inch gravel. The fully automatic batching and mixing plant erected adjacent to the aggregate storage area, Figure 10, included a 2-cubic yard weighing hopper and one 2-cubic yard tilting-type mixer. Batching and mixing facilities were adequate, at most times, in maintaining a sufficient quantity of fresh concrete.

Cement for the work was transported by rail in bulk and in bottom-dump hopper cars to Granby, Colorado, 15 miles from the Granby Pumping Plant. A 1,600-barrel storage silo at Granby and a bucket elevator provided for unloading and storage of the delivered cement. Specially covered dump trucks, which had a capacity of approximately 60 barrels, were employed to transport the cement from the railhead to the pumping plant. Upon arrival, the trucks deposited the cement directly into a road-level hopper and the cement was lifted by bucket elevator to the 500-barrel silo occuping a part of the top

story of the batching and mixing plant. A maximum of two trucks were sufficient in maintaining a supply of cement during placing operations.

Cement was furnished by the contractor, under the terms of the specifications. A recorder, incorporated in the batching plant produced a graphic record of the individual weights of all materials that entered the concrete, except mixing water. This recorder was the basis for payments made the contractor for cement used. Mixing water was measured by means of a water meter. Periodic checks of the batching equipment and recorder were made to insure their accuracy.

Darex, in commercial solution, was used as an air-entraining agent; enough being used to produce 3- to 5-percent entrained air in the concrete. The agent was dispensed, by means of a standard Darex dispenser, directly into the mixer water charging line.

Mixing water was obtained from nearby Soda Creek and pumped into a storage tank adjacent to the mixing and batching plant. During cold weather the water was heated either by an oil water heater or by later installation of a stationary boiler, which was also utilized in supplying hot water for curing and heating within the pumping plant proper. In general water-cement ratios for the concrete on all features averaged 0.50, holding to a maximum of 0.53.

Concrete Handling

Fresh concrete was transported from the batching and mixing plant to the forms in 1- to 2-cubic-yard bottom-dump-type buckets on flat-bed trucks. During the first year of construction, the handling of the buckets at the forms was entirely by draglines, which swung them to the desired location. After erection of the Whirley crane in the Spring of 1948, this rig was employed in the placement of concrete within the plant and in the intake and discharge conduits within its reach. Having a 125-foot boom the crane was able to reach all parts of the plant, and was a welcome addition to the plant equipment in maintaining progress.

Clean-up Prior to Concrete Placement

The preparation of siltstone and base materials to receive concrete has been previously discussed. The clean-up of construction joints to receive fresh concrete consisted at first of wet sandblasting and flushing with air-water jets to remove any laitance or construction debris that may have collected on the previously placed concrete surfaces. Later, however, air and water jets only were used, accomplishing an early cutting of the fresh surface at the first stage of final set. At all times the results desired were not obtained by the air-water jetting, and in these instances the forces resorted to sandblasting. If placement of a subsequent lift was to be delayed, such as that occasioned by a winter shut-down of operations, the joints were sandblasted to a sandy finish, followed by copious flushing with air-water jets. In all instances, joints, either horizontal or vertical, were conditioned by water 72 hours in advance of the placement of fresh concrete.

Placement of Concrete

The first placement of concrete in the pumping plant began June 30, 1947, in the massive substructure.

The fluid pressure the forms would withstand and rate of delivery of fresh concrete, controlled the method of placement in the 8- to 9-foot thick base

slab, involving approximately 3,100 cubic yards. As a result, the fresh concrete was consolidated in 1- to 2-foot stepped lifts to avoid the development of a cold joint. A concrete mix containing 2-inch-maximum size aggregate was used in the substructure and all subsequent placement within the pumping plant and conduits, until the supply of this maximum sized aggregate had been depleted. Concrete containing aggregate of 1-1/2-inch-maximum size was used to complete the work. A mix with a water-cement ratio of 0.53, having a 3-inch slump was best suited for the work, and was found to be sufficiently cohesive to avoid segregation. Concrete was consolidated with both electric and pneumatic vibrators, the pneumatic vibrators being preferred.

The specifications for the work required that the alternate block of the substructure be placed first, and after being properly cooled, the intervening blocks were to be placed. This was done to reduce subsequent shrinkage as much as possible. Late delivery of anchor bolts for butterfly valves necessitated some slight change in the sequence of block placement shown on the plans, but the general scheme of placing alternate blocks was followed throughout. The first placement of concrete above the substructure was in the D-line wall, and work continued on the walls, buttresses, arch rings, and intake block outs without interruption until November 3, 1947, at which time operations were stopped for the winter.

The placement of concrete in the plant was resumed the following season, May 25, 1948, upon completing the erection of the Whirley crane. Cold weather caused a winter stoppage of work on December 10, 1948. Resuming construction for the third season on April 28, 1949, all major exterior concrete work on the building, conduits, and intake structure was completed before cold weather again stopped work. With the walls and roof of the plant building completed, interior work continued throughout the winter by temporary installation of the electric heaters later to be incorporated in the plant heating system.

At first, concrete in the walls and buttresses was placed directly from the buckets whenever possible, but in the narrow walls and the fact that the vertical reinforcement extended so far above the placement under way, made direct deposition impractical. Consequently, a side chute was employed in guiding the concrete into the form. Baffles were used to prevent segregation, and very thorough vibration was required to properly consolidate the concrete and to overcome some segregation that had taken place as the concrete was "screened" by the vertical steel mats. In the latter part of the first season, concrete buggies were employed more extensively to distribute the concrete to the narrow walls, and by this method better results were obtained.

The location of the vertical construction joints in the pumping plant dictated the sequence of placing operations. As mentioned previously, the only vertical construction joints within the plant proper were between the rectangular portion of the plant and arch walls. Horizontal construction joints varied as a rule from 5 to 8 feet. Considerable care had to be taken, therefore, to avoid cold joints within a pour. Placement of fresh concrete in 1- to 2-foot lifts was the general procedure but the slow rate of delivery of fresh concrete required that the contractor's foreman and Government inspectors be alert at all times to prevent a cold joint and stepped placement in 1- to 2-foot lifts was common.

In the placement of concrete in conduits, a somewhat similar procedure was followed. Concrete was dumped by bucket onto chutes inserted in two series of trapdoors in the outside form, one below the spring line and one well above. When the invert and the sides of the forms were filled to the

sills, the lower doors were closed and the concrete placed through the upper ones until a foot or more above the spring line. The upper doors were then closed and the remaining concrete placed and vibrated from the top of the form. There was sufficient room for a vibrator operator between the mats of steel within the conduit forms, except in the 18-inch thick portion of the intake conduit. Very satisfactory consolidation of the concrete with relatively few rock pockets resulted, provided a small amount of concrete was deposited in one place at a time. After the form had been filled the top was screeded and wood floated. The concrete for the conduits was placed at a 3- to 3-1/2-inch slump, and at this slump worked very well. Slumps wetter than 3-1/2 inches caused difficulty in that it "boiled" up within the open invert of the interior form. The placement of the steel plates on the intake-conduit interior forms and the "boil" strip on the discharge-conduit forms described previously reduced this "boiling" tendency considerably, but did not eliminate it completely.

In general, forms within the plant were stripped not earlier than 36 to 48 hours, while those of the discharge and intake conduits were stripped from 12 to 14 hours after placement. In colder weather, forms remained in place somewhat longer, or calcium chloride was employed to a maximum of 1-1 2 percent to secure earlier stripping.

Curing, Cooling, and Protection of Concrete

Specifications provided for the water curing of interior concrete of the pumping plant and all other exposed surfaces. On the unexposed surfaces of the plant, the intake and discharge conduits, etc., white-pigmented curing compound was employed.

To provide for the cooling of the interior of the massive substructure and buttresses, water was circulated through the system of coils installed for the purpose prior to placement of concrete, for a period of 10 days after placement for the substructure blocks and 7 days for the buttresses. Each day the direction of flow within the coils was reversed. Water supplied from Soda Creek was used for the purpose. The temperature of the cooling water tended to become uniform after about the fourth day. It was also required that the blocks of the substructure be cooled at least 7 days before the adjacent blocks could be placed. Afted the cooling was completed, the cooling coils were grouted, under pressure of 100 psi, until completely filled.

The specifications required that concrete exposed to freezing should be maintained at a temperature of at least 50° F for not less than 72 hours after placement, or until hardened thoroughly. It was also required that concrete be protected from freezing for at least 2 weeks immediately after being placed. The protection of concrete to meet these requirements was a burdensome and expensive job, expecially when one looks at the yearly temperature records for the area. On an average, there was only 1 month each year that temperatures remained above freezing. Minor protection of fresh concrete in the area can be needed at any time through June and again after the middle of September. Thereafter, through the following April, elaborate protection is mandatory.

Elaborate steps were taken to secure the required minimum protection from freezing. This included the use of the conventional orchard type salamander, some of which were equipped with electric-powered blowers; air-

plane-type motor warmers; electric heaters with blowers; steam; and during the Fall and Winter of 1948, two coal furnaces were placed in the plant building. Even with these measures and fully housing the plant and other placement locations in canvas, a minimum of protection is all that could be made available. Orchard-type salamanders set on a platform hung on the bottom of the exterior wall forms and surrounded by the canvas spread over the plant wall forms was probably the most efficient for the exterior work, and the electric heaters with blowers for the interior work. Fortunately, with all the heating equipment few conflagrations occurred, although soot, smoke, and fumes were the usual.

Finishing

Specifications for the pumping plant were issued prior to the time that the standard forming and finishing procedures now employed on all Bureau work had been included in Bureau specifications. However, the contractor accepted these new procedures as a guide to the type of finishing desired. These were, therefore, used throughout the construction work. With little exception, all floors within the pumping plant were left 1 to 2 inches below grade to allow for a bonded floor topping. This topping was one of the last jobs completed, after all major construction work within the plant proper had been finished in 1949.

The accumulation of soot and smoke from the heaters provided to protect concrete from freezing, rust stains from curing water, form oil stains, and laitance from a spillage of concrete or seepage of cement laden waters from forms above, made it necessary to treat all exposed surfaces of the plant and other structures permanently exposed to view with some sort of final clean up. As little as possible was required in store rooms, and in locations not generally observable, but the main rooms of the plant building and its exterior above ground level were cleaned by wire brushing, and by wet and dry sandblasting. Where it was possible to seal off effectively a portion of the building or a room, or where dust from dry sandblasting operations were not a hazard, this method was used. It was most effective and at less cost than the wet sandblasting of the interior walls where sand in the air was objectionable.

Embankment and Backfill

Materials stock piled from excavation were utilized wherever possible in the construction of embankments and in backfilling around and over the various structures. The Soda Creek Diversion Dike was zoned, using in the interior or impervious zone a sand with excess silt and clay and a gravel with sand-clay binder excavated from the abutments and diversion channel, and supplemented from an adjacent borrow pit. The upstream and downstream zones were graded from sand, gravel, and cobbles, to boulders on the exterior faces, compacted by tractor and truck traffic.

The more pervious silty-sandy gravel and cobbles from the plant and intake conduit excavation, supplemented by similar materials from an adjacent borrow pit, were utilized as sluiced fill material over the intake conduits and around the plant building. The material was sluiced or puddled into place in 2- to 3-foot lifts, receiving only the amount of compaction resulting from truck and tractor traffic. Boulders were utilized to riprap the face of this fill on the reservoir side.

Loose backfill from excavation was placed around and over the discharge conduit.

Construction Control

The excavation for the pumping plant, the conduits and the intake structure were slope staked from their respective centerlines and were properly referenced. The horizontal control for the pumping plant was established for each reference line by monuments on each side of the structure. All bench marks about the pumping plant were set from a circuit between two Reclamation precise-datum bench marks. All construction points were set by the intersection of two reference lines, and the proper elevation set from nearby bench marks. One crew of three to four men established this control and set all points for the construction work.

The inspection of the actual construction work and the placement and handling of the concrete for the pumping plant and conduits and the diversion dike and channel were provided by Bureau personnel at the pumping plant. The handling of the aggregate for the concrete and the inspection within the batching and mixing plant were under the supervision of the Bureau technicians and inspectors of the area laboratory, who also performed the necessary testing of concrete and made routine aggregate moisture and grading tests.

Personnel

Design and construction of the Colorado-Big Thompson Project, of which the Granby Pumping Plant is a part, is under the direction of Chief Engineer L. N. McClellan. Avery A. Batson is Director of Region 7 and James H. Knights is District Manager of the South Platte River District within which the work was accomplished. Construction within the area was under the direction of Construction Engineer George R. Highley until February 1950, at which time he was succeeded by U. V. Engstrom. The writer, as Field Engineer and later Assistant Construction Engineer was responsible for construction details in the Granby area also until February 1950. C. S. Scribner, now Field Engineer in the area, was Resident Engineer at the pumping plant, and J. S. Fulton was his principal assistant.

Mr. E. H. Honnen, as Project Manager, was in charge of the work for the Granby Constructors. He was assisted on excavation by Superintendent Clay Hoon. Charles Clapp was superintendent of form and concrete work during 1947. Fred Brandt succeeded him in 1948 and completed the work.

Figure 1--Shovels were able to excavate the siltstone bedrock without undue difficulty and very little prior blasting.

Figure 2--Final trimming and preparation of the plant foundation was by power spades and hand tools.

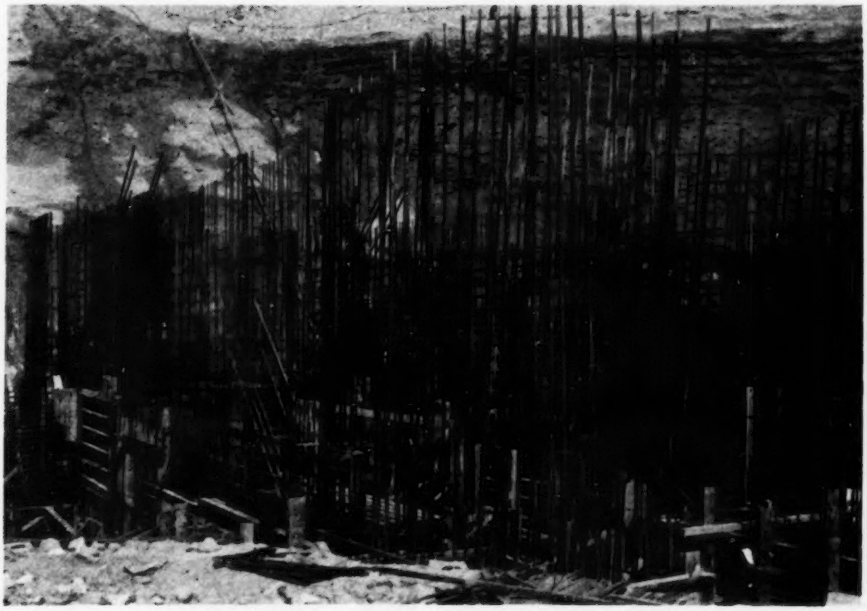

Figure 3--The heavy reinforcement on 4-inch centers vertically, horizontally, and diagonally, and extending above the forms, complicated concrete placement and handling of forms and other construction materials.

Figure 4--Shop-fabricated panels for the substructure were sheeted in a horizontal direction with 6-inch shiplap and braced externally.

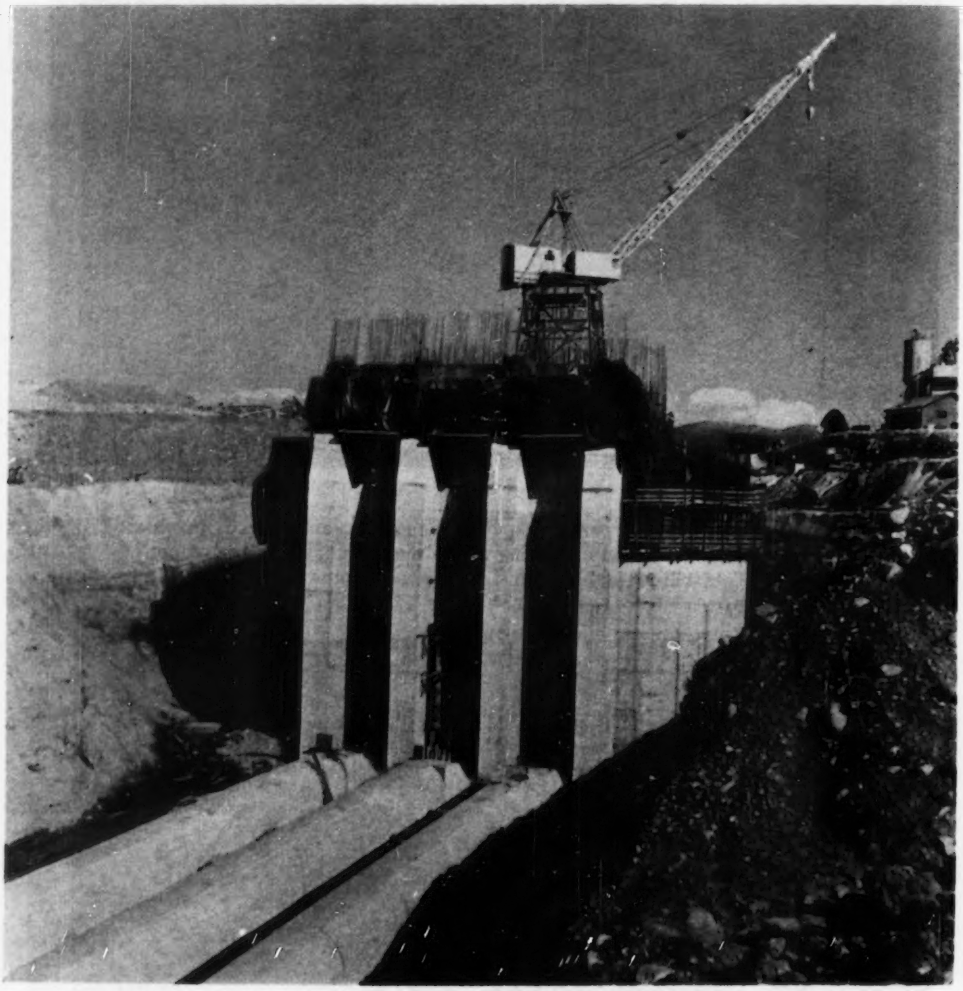

Figure 5--The "whirley" crane transferred concrete buckets from truck to forms in all parts of the plant building.

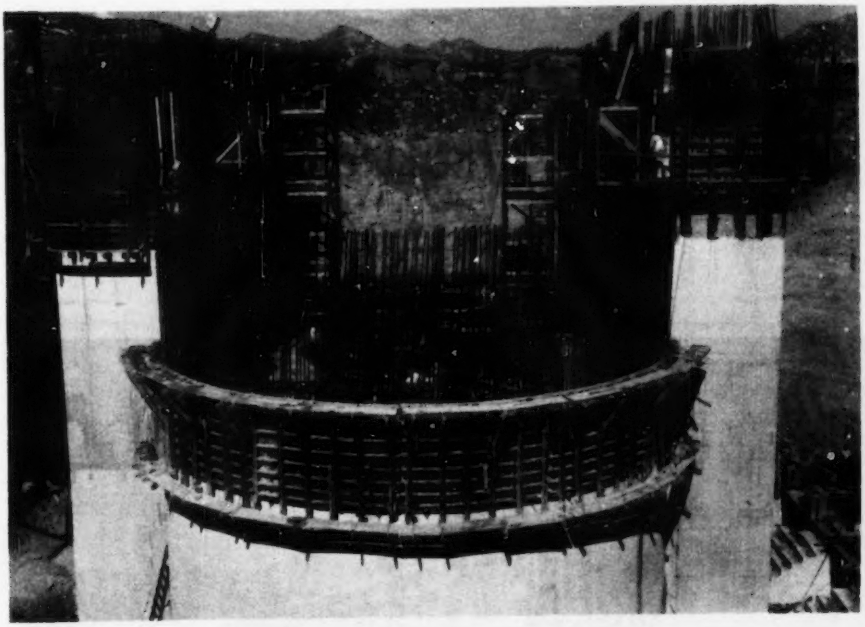

Figure 6--Forming arch rings and exterior walls and buttresses.

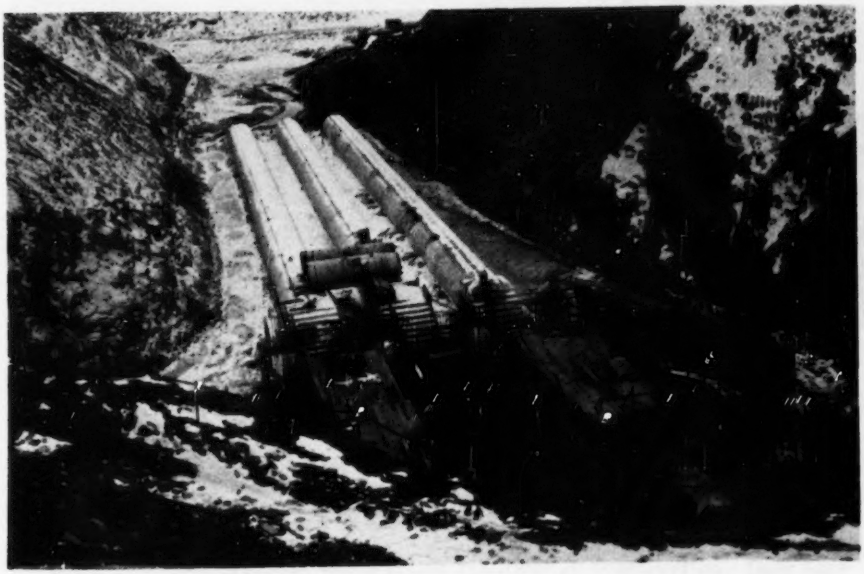

Figure 7--The stage of construction at the end of the first season, showing major excavation, the first few lifts in the plant and the heavier portion of the intake conduit complete.

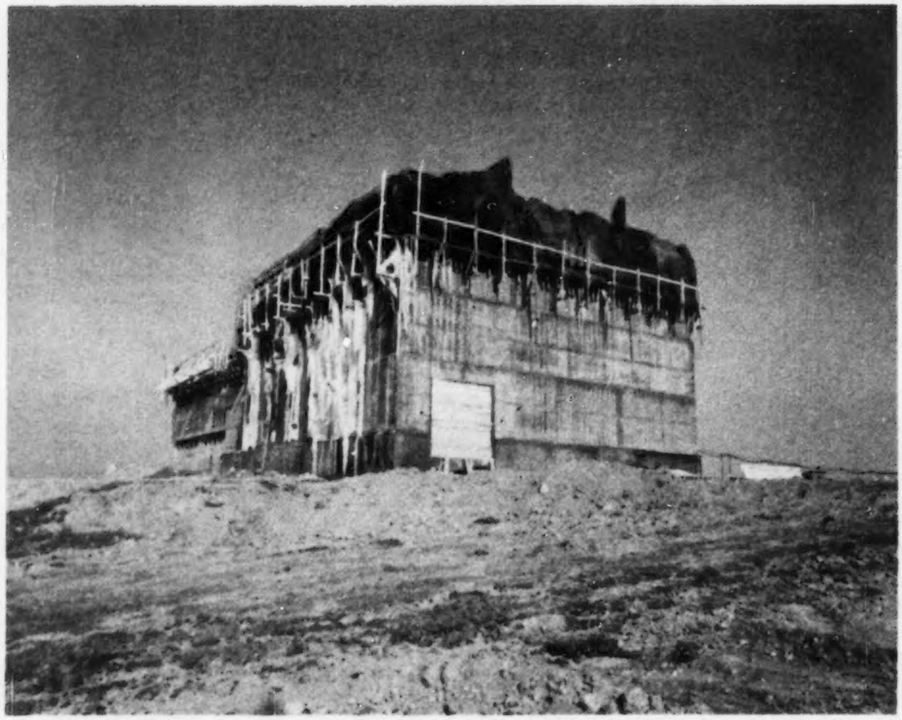

Figure 8--Protection of concrete from frost and freezing was a major task.

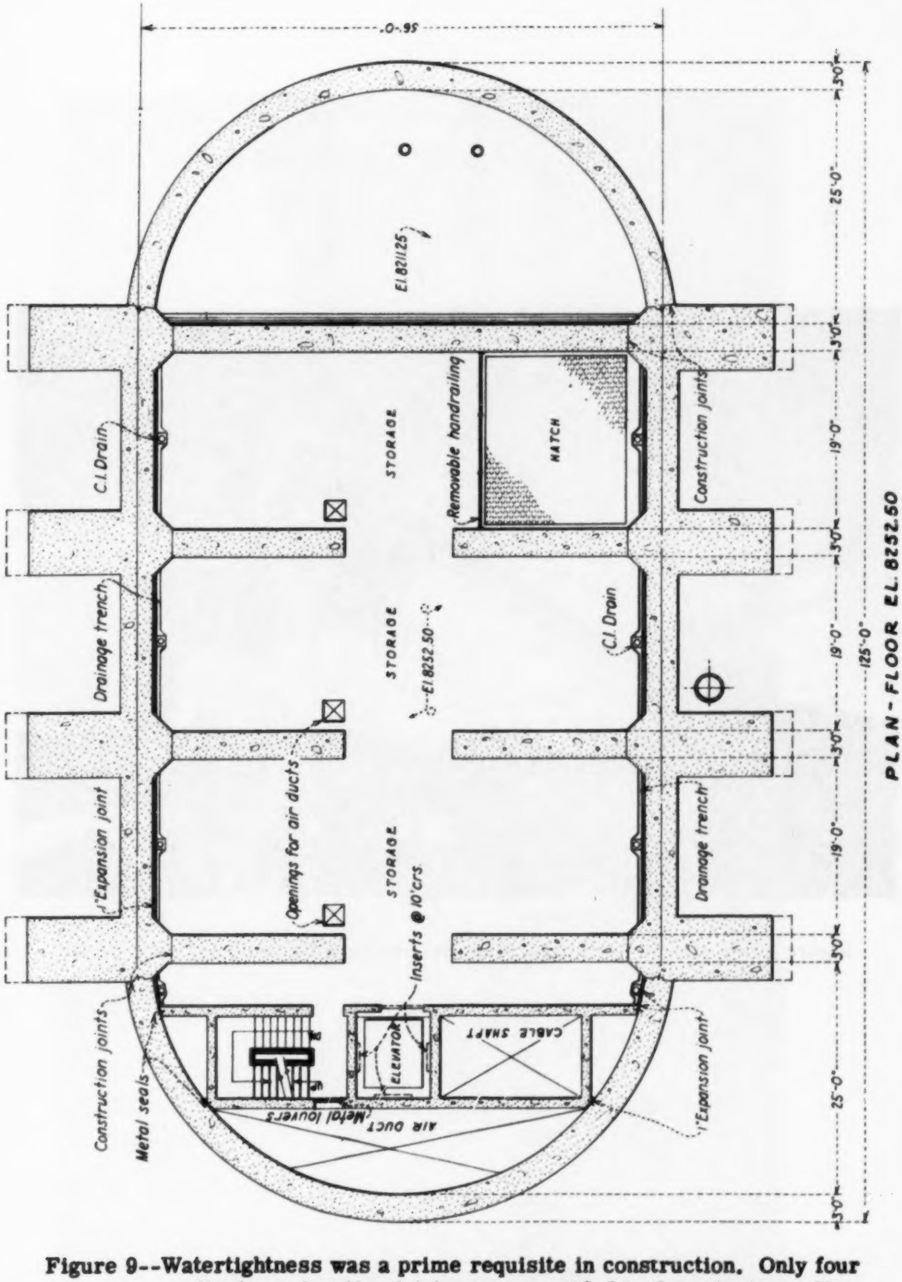

Figure 9--Watertightness was a prime requisite in construction. Only four vertical construction joints were provided in the exterior walls; they were between the arch rings and rectangular section. Metal seals were provided for these joints.

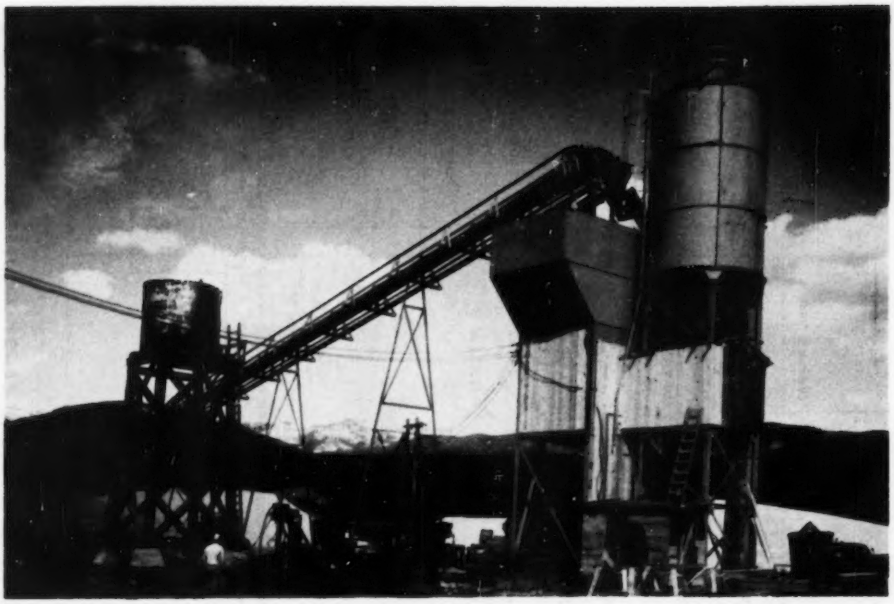

Figure 10--A fully automatic batching and mixing plant furnished all concrete for the work.

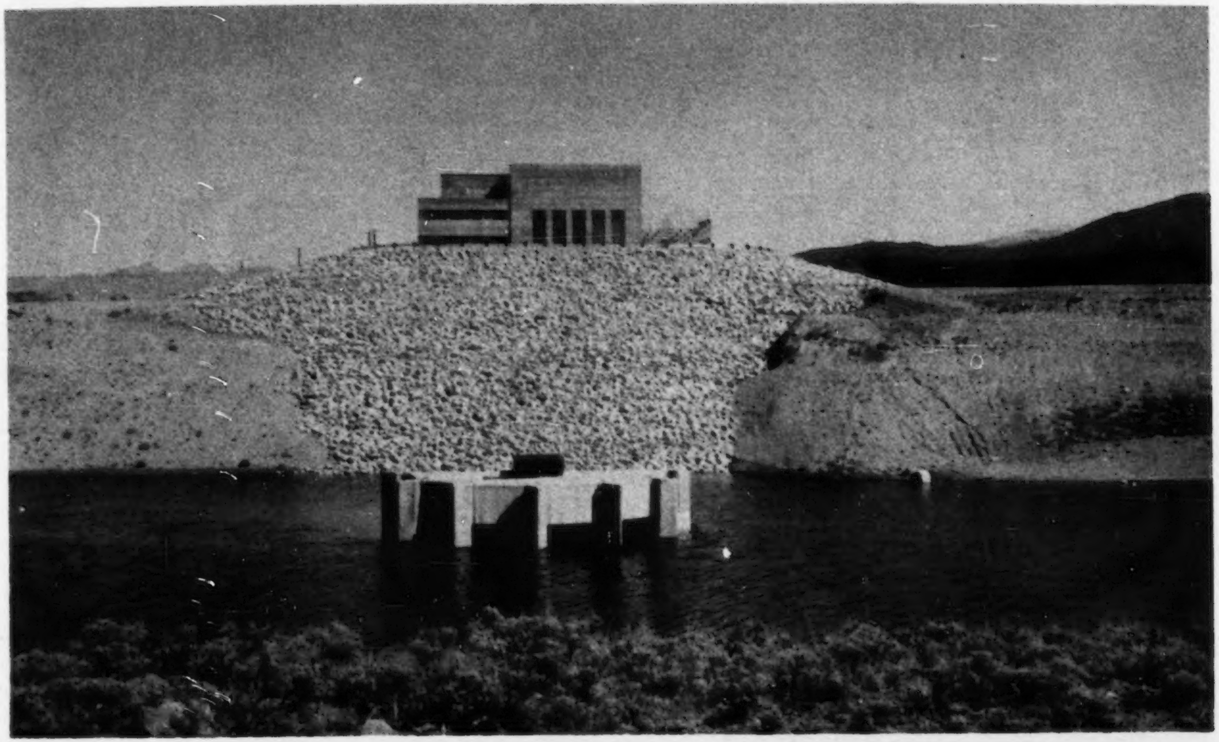

Figure 11--The completed structure with the intake structure in the foreground nearly inundated.

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